Radiometric alignment and vignetting calibration

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Overview

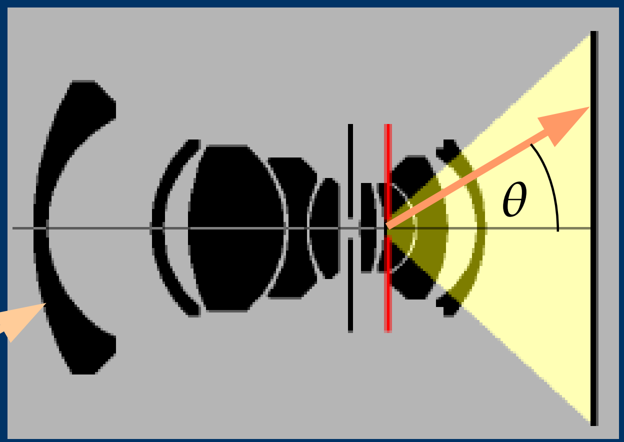
- Motivation
- Image formation
- Vignetting and exposure estimation
- Results
- Summary

Motivation

- Determination of vignetting and exposure
- Traditional approach
  - Flatfield + camera response calibration in the lab
- Simpler: use overlapping images

- Applications
  - Spatial & photometric mosaicing
  - Recovery of scene radiance, required for radiometric reconstruction methods (Shape from Shading, Photoconsitency)

Image formation



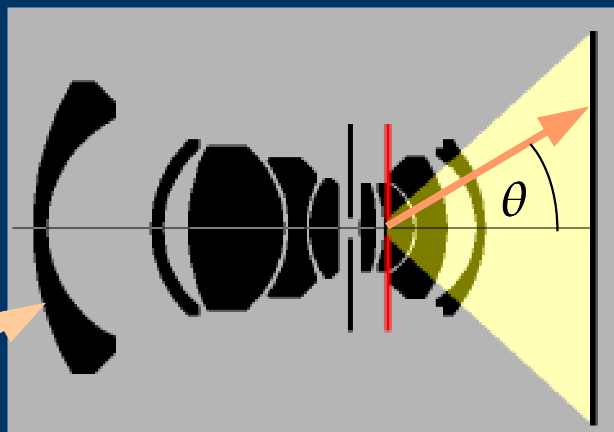
Radiance L in $[\frac{W}{sr\,m^2}]$

Irradiance I in $[\frac{W}{m^2}]$

- Image irradiance: $I = \frac{\pi}{k^2} M\ L$
- Natural vignetting: $M = \cos^4 \theta$

k	aperture value
M	vignetting function

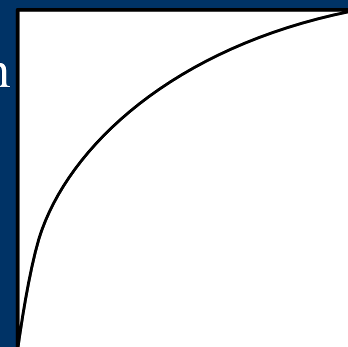
Image formation



Radiance $L\left[\frac{W}{sr\,m^2}\right]$

Irradiance $I\left[\frac{W}{m^2}\right]$
in image plane

Integration
stI



Camera response
$f(w_i eML)$

Pixel values B_i
in [colour levels]

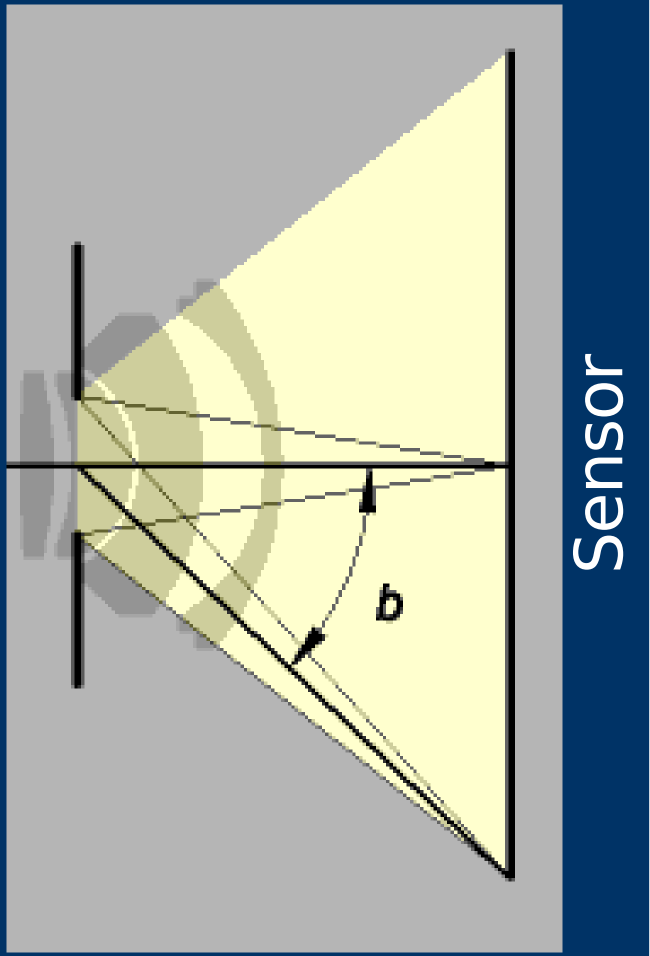
- Integration on sensor
- Used model

$$\boxed{B_i = f(w_i eML)}$$

$e = st\frac{\pi}{k^2}$	effective exposure
M	vignetting function
w_i	white balance factor
i	channel number
k	aperture value
s	camera sensitivity
t	integration time

Natural vignetting

- Light falloff due to
  - Apparent area of exit pupil, cos(b)
  - Larger effective area on film, cos(b)
  - Larger distance to image corner, $\cos^2(b)$
- Natural vignetting not reduced by stopping down
- Lenses are complicated, $\cos^4$ does not apply for many designs



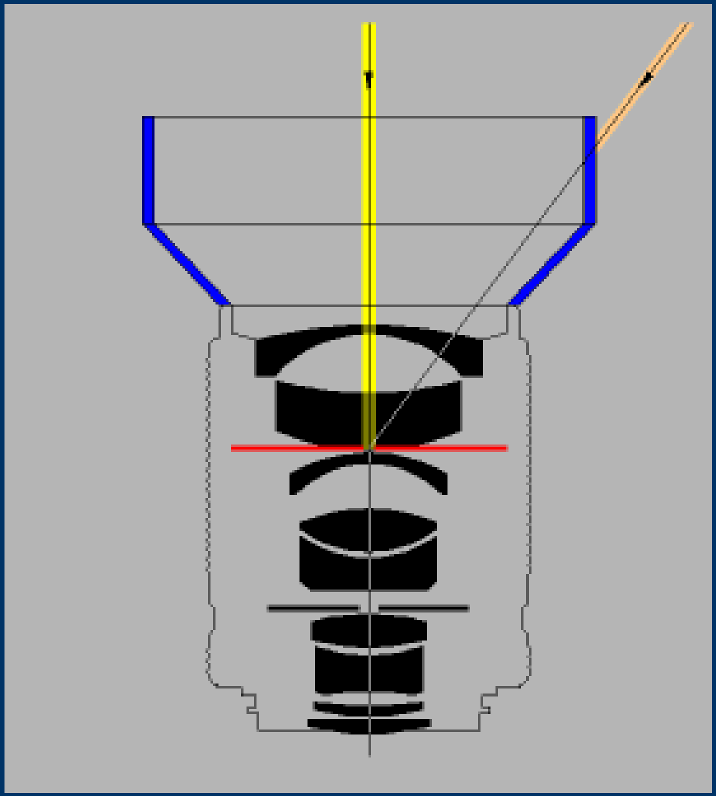
Optical vignetting

- Entrance pupil shaded by lens barrel
- Optical vignetting depends on aperture

f 1.4 f 5.6

Mechanical vignetting

- Light is blocked by lens hood, or other objects
- Results in unrecoverable vignetting



Vignetting of a real lens
Flatfield image

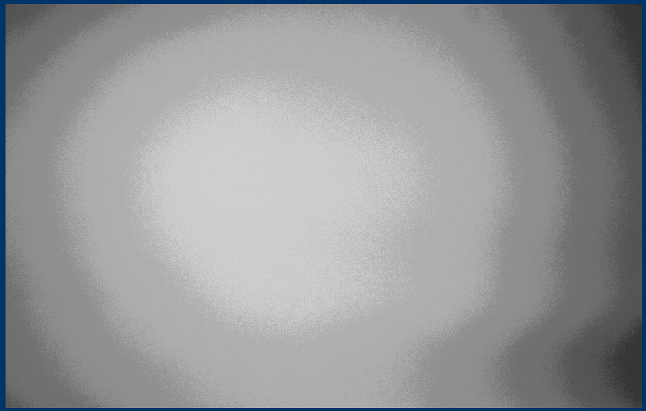
- Image of a homogeneous white surface

- Observation
  - Radial falloff
  - Not centred

Image by Goldman and Chen (2005)
Contrast enhanced and quantized for better visibility on a beamer

Modelling vignetting

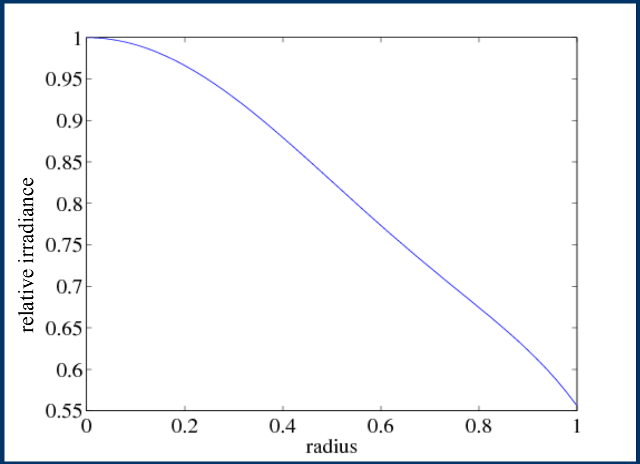
- Non-Parametric models
  - Flatfield image
    - accurate
    - acquisition cumbersome



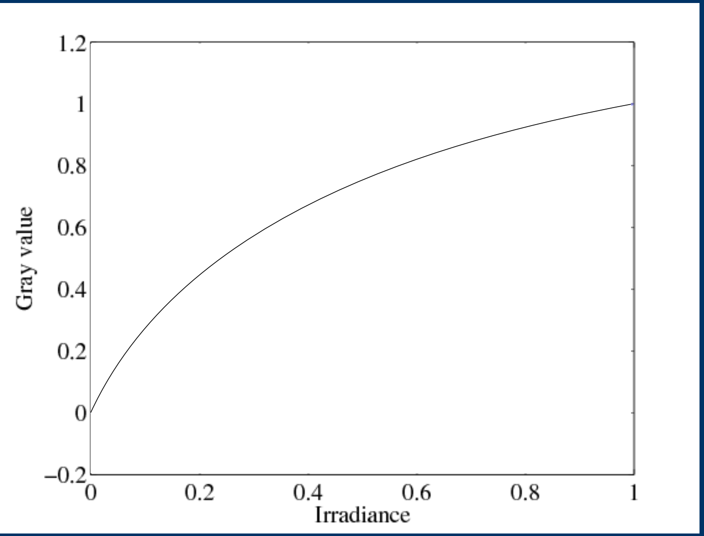
- Parametric models
  - Radial polynomial model

$$M = \beta_1 r^6 + \beta_2 r^4 + \beta_3 r^2 + 1$$

  - Allow center shift c



Modelling the camera response



- Non-Parametric
  - Can model all shapes
  - Dense data required
- Parametric
  - Polynomial
    - Less parameters
    - Dense data required
  - PCA basis of 201 response functions (Grossberg, Nayar)
    - First 3 Eigenresponses describe all 201 functions well.
    - Strong model, can be used with sparse data

Grey value transfer function

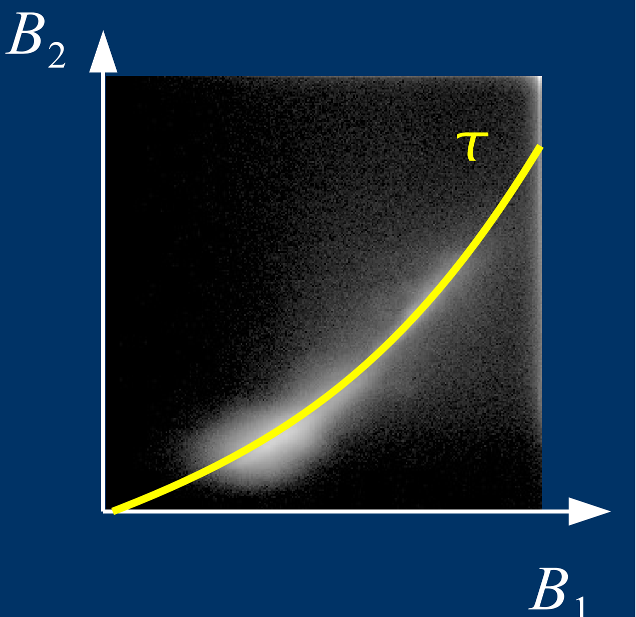
- Scene points imaged in registered images

$L_1 = L_2$

- Joint histogram
  - cannot model vignetting

- Gray value transfer function

$$B_1 = \tau(B_2) = f\left(\frac{e_1 M(x_1) f^{-1}(B_2)}{e_2 M(x_2)}\right)$$



Estimation using corresponding points

- Estimation of the transfer function by minimising

  $$e_t = d(B_1 - \tau(B_2))$$

- Other approaches (Goldman 05)
  - Alternating minimisation steps of

    $$e = \sum_j d(B_j - f(e M L_j))$$

    for L and e,M,f
  - Large number of variables
  - Slow convergence

$L_1 = L_2$

d distance metric

Estimation using corresponding points

- Estimation of the transfer function by minimising
  $e_t = d(B_1 - \tau(B_2))$
- Symmetric transfer error:
  $e_s = d(B_1 - \tau(B_2)) + d(B_2 - \tau(B_1))$

- Minimising e_s using a set of (B_1, B_2) measurements yields
  - Exposure, vignetting, white balance
  - Camera response

d	distance metric

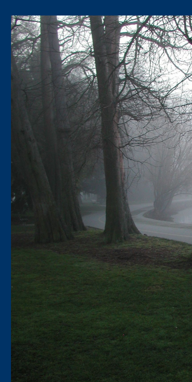
The exponential ambiguity

- Simultaneous estimation of exposure and camera response subject to exponential ambiguity
- Calibration and Radiometry
  - Either camera response or exposure need to be known
- Removal of exposure, vignetting and WB differences
  - Find any solution, correct images
  - Use inverse response to transform into original grey value space

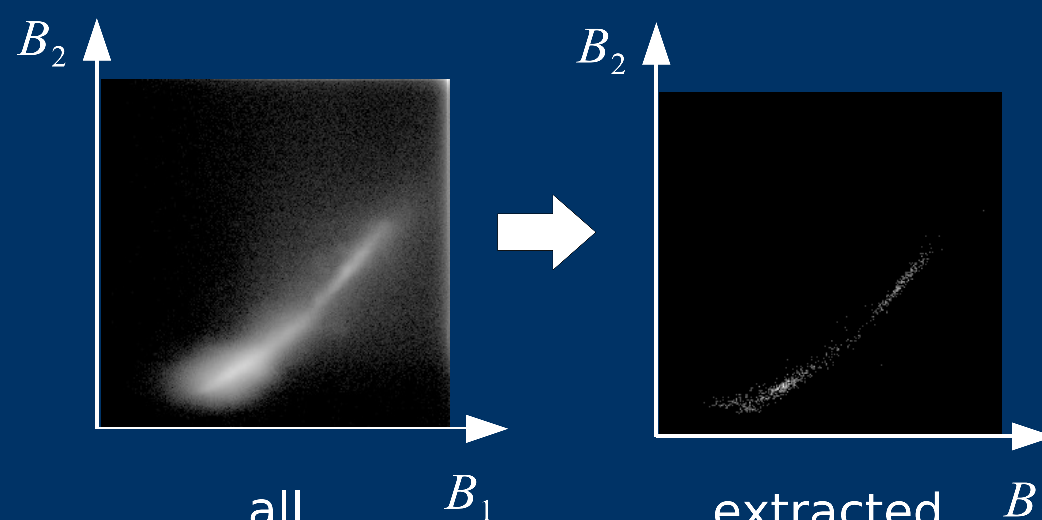
Extraction of corresponding points

- Avoid outliers due to misregistration
  - Extract points in low gradient areas
- Need points at all radii r
  - Bin points by distance from image centre
  - Select points with lowest gradients

I_1



I_2

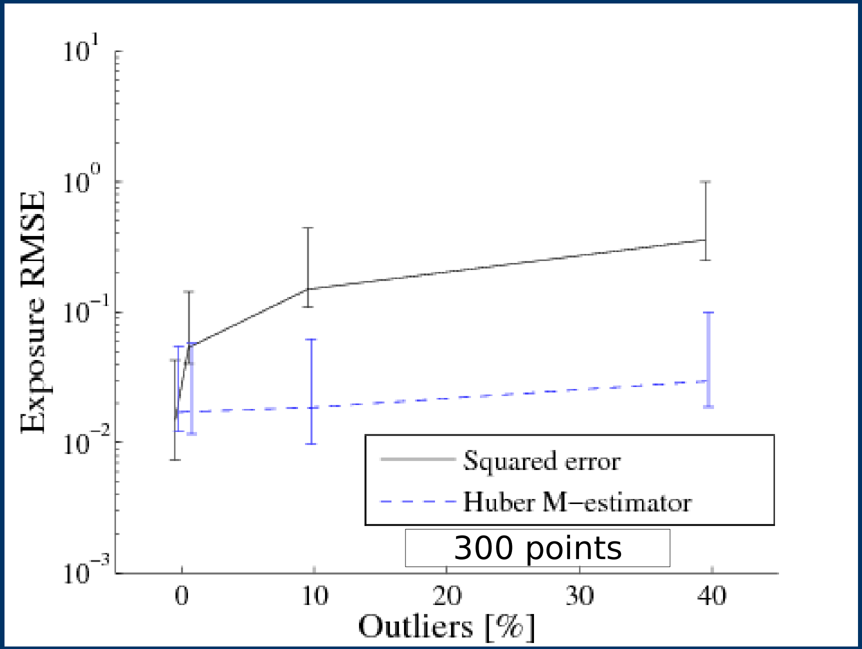


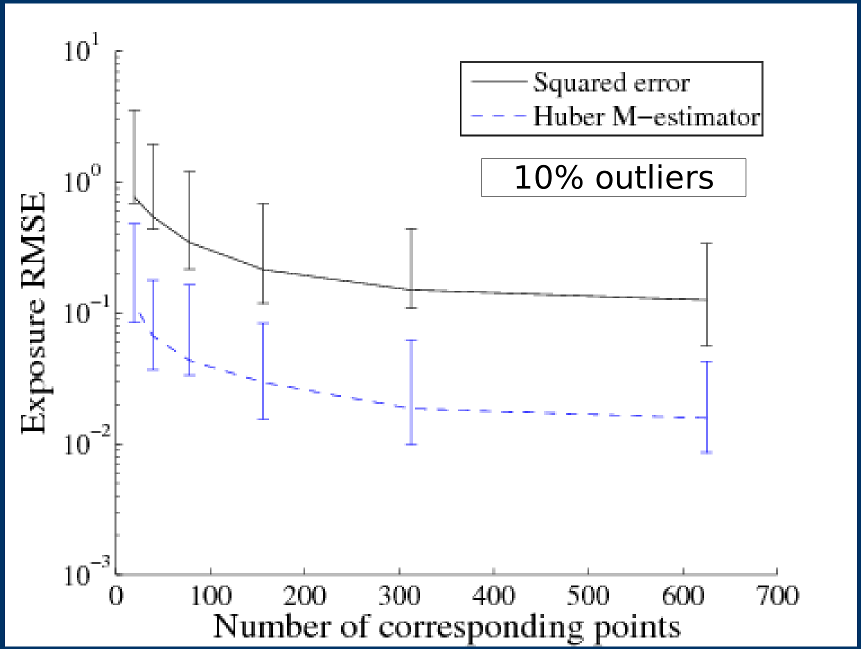
all correspondences

extracted correspondences

Evaluation
Synthetic example

- Simulated panorama with 6 overlapping images
  - Gaussian noise (2 grey values), quantisation, outliers
  - Estimate vignetting and exposure, analyse error to ground truth





Venice
Vignetting correction

Green Lake
Vignetting, exposure and WB correction

Original images

Corrected images

Green Lake
Results Goldman & Chen

Spherical panorama
Original images

Spherical panorama
Vignetting, exposure and WB correction

Summary and conclusion

- Estimation of radiometric camera parameters from overlapping images
  - exposure, vignetting, response curve, white balance
  - Robust approach, better results than previous methods
  - Compact parametrisation, fast estimation
- Applications
  - Radiometric calibration, estimation of scene radiance
  - Removal of photometric distortions from image mosaics

- Implemented in Hugin, http://hugin.sf.net

Radiometric alignment and vignetting calibration

by

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Evaluation
Image blending